FEASABILITY OF BACTERIAL CELLULOSE IN FURNITURE DESIGN

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bachelor thesis

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Interior architecture
spring/2017

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PHOTO 1

ABSTRACT AND KEYWORDS

This research is based on ChemArts Summer Schools (2016) final project “Grow Your Lamp!”, that had great interest and was exhibited in Aalto University`s Learning Centre and as well in Helsinki Design Museum. The study was executed because there is too little knowledge about bacterial cellulose used in furniture design and what could be the strengths and the limitations of the material.

Environmental sustainability has posed the need for great development into grown fibres and materials within the interior design industry. This thesis describes and evaluates the feasibility of bacterial cellulose as a possible solution for use in this industry.

The theses will serve as basic information on how to grow and produce the material, as there is little to no information on how to grow it for design purposes. It covers the basic as well as the most important properties of bacterial cellulose as sustainability and biodegradability.

Acetobacter xylinum is a cellulose producing bacteria which under the right conditions will self-organise into a nano-structured, textile-like material called bacterial cellulose. The growth period was low in terms of productivity. Less than 1 metre of the fabric could be grown in three weeks. But what the material lacks in economic viability it most definitely makes up in terms of sustainability and biodegradability.

The combination of recyclability, sustainability, biodegradability and new end-use opportunities makes cellulose the potential super material of the future. The use of ethical bio-materials materials impact functionality, aesthetics and ethics of the product.

Due to the materials high mechanical strength and leather like appearance, it could be possible to use the material as a part of a seating furniture, as they require this kind of property to carry a weight of average man.

The materials stability to endure high temperatures makes it safe to use in lights and even in close contact with light sources. Making it the extremely suitable material when designing lights.

This research found out that the limitations of the materials are the low economic viability due to materials long growth period.

Keywords: *Bacterial cellulose, microbial cellulose, cellulose, bio design, sustainability, bio materials, furniture design*

1.1 Aims and Significance

The aim of this research is to explore the feasibility of leather-like bacterial cellulose in lighting design. The research will concentrate in bacterial cellulose and its properties in terms of sustainability, everyday usability, physical properties and economic viability.

The significance of sustainability and eco-friendliness within the furniture and spatial design industry is an ever-present and growing field of research and innovation. With this there has come the developed interest and increasing demand for compostable materials that can be produced with minimal raw materials, toxins and water.

I strongly believe that all designers have great responsibility to use and research about new materials in their work because materials impact functionality, aesthetics and ethics of the product. Properties like sustainability and biodegradability is something every designer should weight in the beginning of their design process.

> *"There is increasing demand for compostable materials that can be produced with minimal raw materials, toxins and water, however there is currently no home for all the research, experiments, projects, and inspiration around 'grown materials' to meet this need. Without such a platform, innovators will continue to work at small scale, and potentially world-changing innovations will remain hidden to the global community* (Lee, 2017)."

Wooden- and plant-based bio materials like the different types of cellulose could be the leading bio materials in Finland as 75% of the country is covered with forests, making it the most forested country in Europe. The amount of timber in Finnish forests increases every year. Annual fallings have for a long time been smaller than growth. (Finnish Forest Association, 2014)

It is such a pity that we as furniture design students, know so little about renewable wooden based bio-materials. Therefore, the thesis carries great significance as initial information source for young designers that would want to make a difference with their work.

1.2 Research Question

What are the strengths and limitations of bacterial cellulose when used in furniture design?

2. LITERATURE REVIEW

After initial difficulties of finding appropriate literature to support my thesis. The main use of bacterial cellulose is in medical field and therefore there were mostly available sources from the field of biology and chemistry. One of the sources was Rani, Udayasankar and Appaiahs article on Properties of bacterial cellulose that gave important insight on the properties of the material but mostly being about wound dressing capabilities and therefore not entirely useful for me.

The field of sustainability is highly published and I have used the books like "Sustainable Design" by D. Bergman to define what is eco-design and get first insight of sustainability theories like Cradle-to-Cradle and three R-s. To deepen my knowledge of these theories I read the book" Cradle To Cradle" by Michael Braungart and William McDonough.

Buckminster Fuller compares the Earth to a spaceship in "Operating Manual for Spaceship Earth" he stated that we are currently on a spaceship that started its journey with a finite amount of supplies and it cannot be restocked. I think that he's book is the original way on explaining sustainability by creating a very brilliant metaphor.

"Bio Design" by William Myers served as catalogue, shortly introducing the latest designs and designers on field, as for the bacterial cellulose there was mentioned Suzanne Lee`s Biocouture and some basic information on growing bacterial cellulose.

The most useful of all the sources on biomaterials was Sasha Peters`s "Material Revolution 2" as it also features furniture made of bacterial cellulose on addition of the Biocouture jacket.

3. THEORY

3.1 What is cellulose

Cellulose is very abundant material that is found in nature and is mainly produced by plants, but it is also possible to grow it at home using fermentation method by Acetobacter bacteria. It is a structural component of plant cell walls, which is considered sustainable, renewable and multifunctional. Due to its abundance, biodegradability and sustainability, new methods of using cellulose have become an active research topic alongside more traditional wood or cellulose based products. The combination of recyclability and new end-use opportunities makes cellulose the potential super material of the future. (Wikipedia, 2017)

PHOTO 2

3.1.1 Different Types of Cellulose

NANO CELLULOSE

Cellulose Nano fibrils are generally manufactured from wood pulps, but annual plants offer an alternative source. CNFs are manufactured by mechanical treatments, for example by grinding, homogenization or micro-fluidisation. During mechanical treatment, the micro fibrils forming the fibre cell wall are separated from each other, and as a result a viscous gel is formed, consisting of individual nano-scale fibrils with width generally between 20-40 nm and length of several micro meters.

Cellulose nanomaterials have many unique properties making them potential for numerous applications. The most important properties of cellulose nanomaterials are their strength, rheological properties, reactivity and tendency for film formation. In addition, they are produced from renewable natural resources and according to the present knowledge, are safe to produce and use (Design Driven Value Chains in the World of Cellulose, 2014). (Photo 3)

PLANT BASED BACTERIAL CELLULOSE

Plant based bacterial cellulose similar like the bacterial cellulose that is found in Kombucha leather. Plant based bacterial cellulose is found in almost all plants: algae, mushroom, grass and plants etc.

HOME PRODUCED BACTERIAL CELLULOSE

During the fermentation of sugar, a process by which bacteria gain energy, some strains spin micro fibrils of pure cellulose. These adhere to each other, eventually producing a dense but flexible layer. (Photo 2) Then the piece of starter culture containing bacteria and yeast, are added to sweetened tea. (Myers, 2012) After one week the thin film is noticeble on the surfice and in 3-4 weeks it have reached the desired thickness for harvesting, about 2 cm.

The leather like texture appears when dried. The material could be shaped on mold or dried flat on wooden board and it has self-sealing properties.

PHOTO 3

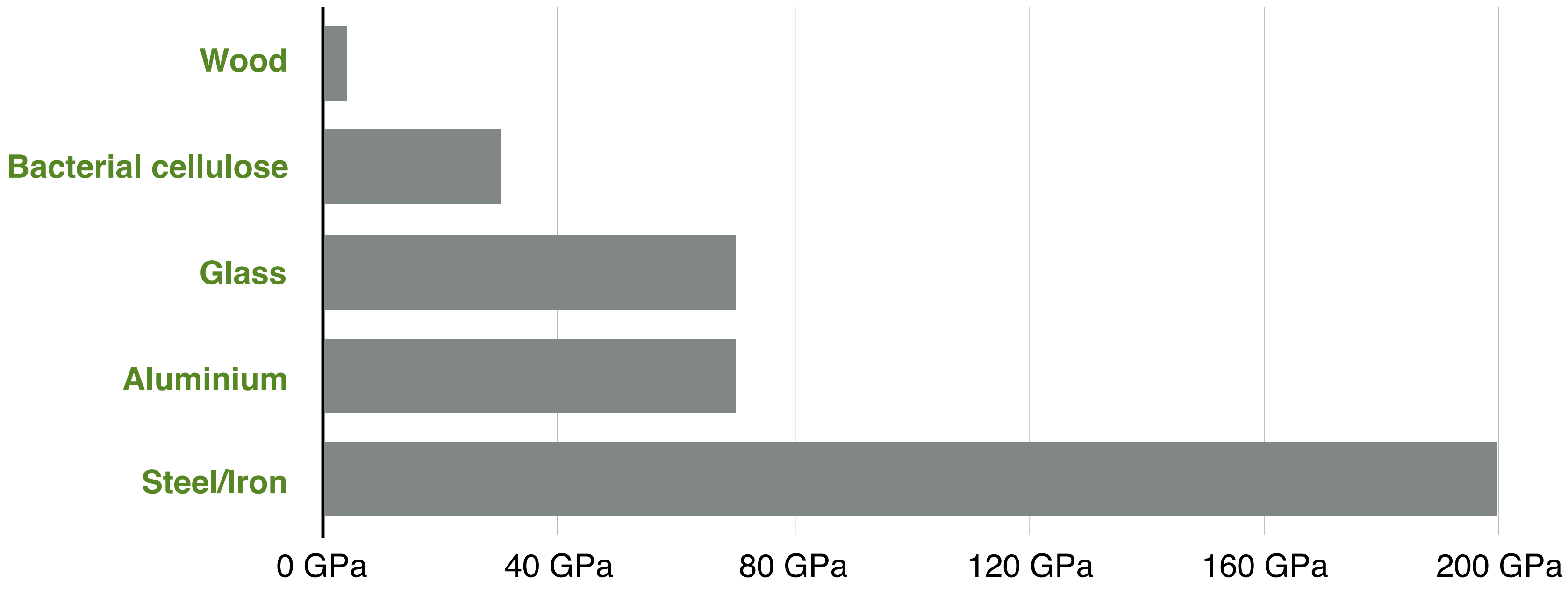

CHART 1: elasticity of different materials

3.2 Advantages of Microbial Cellulose Over Plant Cellulose

Bacterial cellulose is essentially finer than its plant-based counterpart and contains no disruptive additional substances. It is based on a highly complex, three-dimensional nanostructure, which gives the material outstanding mechanical properties. Particularly worthy of note is Bacterial Cellulose`s high mechanical stability when wet, which is comparable to steel**.** (Peters, 2014)

3.3 Physical Properties and Well-known Use of Bacterial Cellulose

Bacterial cellulose displays many unique properties including high mechanical strength, highly crystalline, and an ultra-fine highly pure Nano fibril network structure with stability toward chemicals and high temperature. In native state, bacterial cellulose has greater hydration, holding over a 100 times its own weight of water (Rani, et al., 2011).

The great liquid-absorption ability is a result of the broad space between the different fibres, creating a large surface area, while the high mechanical strength is due to the inter-fibrils hydrogen bonds, which give stability to the structure (Scionti, 2010).

In drying process of bacterial cellulose, the nanofibers arrange parallel to each other and form layered sheets. These give the dried cellulose sheets high stability and strength, as there is the formation of more hydrogen bonds among the fibres (Scionti, 2010).

The first mechanical tests on Bacterial Cellulose were conducted by Yamanaka in 1989 and the dried material was tested in sheet form, with Young's modulus up to 15 GPa. Later, values of modulus of around 30/40 GPa were reported by Nishi in 1990 (Scionti, 2010).

Young module is a measure of stiffness to determine the elasticity of materials. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material. (Wikipedia, 2017) (Chart1)

3.4 What is Biodegradability

Biocompatibility is the ability of a material to perform with appropriate host response in a specific application (Williams, 1987). Meaning that biodegradable material turns to soil when inserted in one, over period of time and no chemicals are needed for the process.

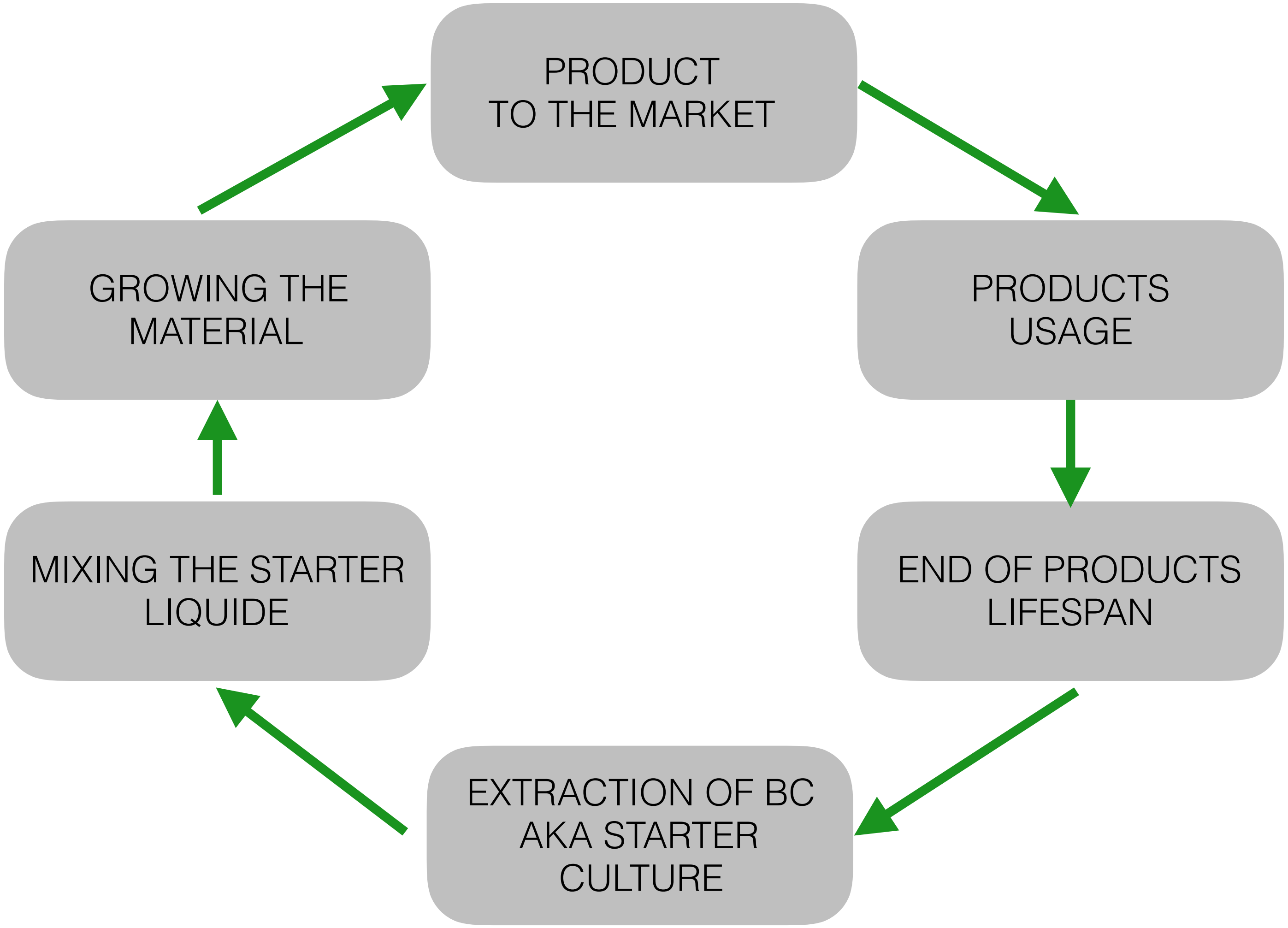

FIGURE 1: Cradle-to-Cradle model of bacterial cellulose

3.5 What is Sustainability and Sustainable Design

The word “sustainability” refers to systems and processes that can operate and persist on their own over long periods of time. If you look up the adjective “sustainable” in a standard dictionary, you will find definitions such as these: “able to continue without interruption or diminution,” “able to endure without failing,” and “capable of continuing for a long time.” (Bergman, 2012)

The noun “sustainability” is typically used about systems that support life on earth. The Oxford English Dictionary defines the ecological meaning of “sustainability” this way: “Of, relating to, or designating forms of human economic activity and culture that do not lead to environmental degradation, especially avoiding the long-term depletion of natural resources” (Simpson and Weiner 2009).

Buckminster Fuller compares the Earth to a spaceship in “Operating Manual for Spaceship Earth” he stated that we are currently on a spaceship that started its journey with a finite amount of supplies and it cannot be restocked. (Fuller, 2008) I Think it’s very brilliant comparison and makes us understand the situation better. There aren`t infinite supplies on earth and most of the materials do not get replenished from outside. Only the solar energy, wind and biofuel are constantly replenished and as well as bio materials. We should not design objects using unsustainable materials. To be truly sustainable we should not waste the Earths recourses faster than it`s ecosystem can replenish them. (Bergman, 2012)

3.5.1 Cradle-to-Grave and Cradle-to-Cradle Thinking

Eco-design has evolved considerably from its 1960s origins, captured in the phrase “Reduce, reuse, recycle.” (Bergman, 2012) Nowadays there is more to eco design than just three R-s. We can do more than that when we stop limiting our goals. Therefore, the concept of eco-design must be broadened.

Life cycle analysis, also known as life cycle assessment, has been applied to products. The life of the product is examined from cradle to grave; that is, from the origin of its raw materials to the manipulation of these materials during manufacturing, to the consumption of energy and recourses during its useful life, to the impact of its eventual end of life (Bergman, 2012).

At each phase of the life cycle, there are material and energy impacts. A Life Cycle Assessment attempts to quantify these inputs and then come up with values to represent their impact. By analysing the results, a designer can evaluate where to improve or modify a creation (Bergman, 2012).

The cradle- to-grave approach still has limitation. The word grave implies that the product has a linear life span. Therefore, it enables us to see and reduce the overall impact of what we design, but it does not get us

PHOTO 4

to the goal of sustainability.When we expand our thinking from cradle-to-grave towards cradle-to-cradle, we put cycle back into life and archive true sustainability.

4. METHOLOGY

4.1 DWoC and ChemArts Summer School

So far, the main use of cellulose has been to produce paper. Design Driven Value Chains in the World of Cellulose or DWoC is a multidisciplinary research collaboration project focused on finding new and innovative applications for cellulistic materials. Their aim is to utilize cellulose in highly refined products like textiles, fashion, interior design, health products, architecture and construction. (Design Driven Value Chains in the World of Cellulose, 2014)

In summer of 2016 I took part of the ChemArts summer School organized by DWoC, the theme of that interdisciplinary course was cellulose and other cellulistic materials. The concept of "Grow Ur Own Lamp!" started there and I presented the first prototypes in final critique in last week of August 2016.

After the course finished I did continue to work on my own to perfect the design by adding wooden parts holding the bacterial cellulose shades.

The curator of the opening exhibition in renewed Learning Centre chose my pair of luminaires to exhibition "Unexpected Encounters" that took place from 1st of November to 14th of December 2016.

The pair is also presented in Helsinki Design Museum`s recent exhibition "Enter and Encounter" from 24th of March till 22nd of October 2017.

4.2 Growing the Bacterial Cellulose

That have been done for centuries when brewing the Ancient health drink called Kombucha. The symbiotic colony of bacteria and yeast (SCOBY) that grows on the surfice of the drink is the bacterial cellulose and have leather-like texture when dried. It grows on surfice and takes the shape of the container, howewer the amount of liqude is not in correlation with the harvested material.

During bio-based production process, microbes like Acetobacter are used to convert glucose into cellulose within a fermentation process, producing a gel-like textile surface with thickness of up to 400 mm. (Peters, 2014) (Photo 4)

The growing of the microbial cellulose was an essential part of my ChemArts summer project. It involved brewing the liquid, adding the kombucha, growing and harvesting, and finally drying, to produce a fully formed fabric film. The growth prosess was monitored by me and bubbles were removed as they appeared.

PHOTO 5

The detailed method for the growth of Kombucha leather is explained below;

INGRIDIENTS

2l of water

200g of white sugar

4-6 teabags (green or black)

one piece of SCOBY or the starter culture

200ml vinegar or unpastourized fermented kombucha tea drink

METHOD

1 Heat the water to boiling temperature of 100`C

1 Mix in the sugar to the boiling water until it dissolves compleately.

2 Add teabags and let them to soak for 15-20 minutes

3 Cool down the sweet tea mixture to 30`c or below

4 Pour in either the vinegar or fermented Kombucha

5 Introduce the Scoby and pour in container,
making sure that the liquide is at least 2-3cm deep.

6 Cover the container with breathable muslin cloth and tighten up
with a rubber band. (Photo 5)

7 Keep in warm and well ventilated area and give it 3-4 weeks to
grow the desired thickness.

8 Rinse well and dry the material. (Photo 5)

PHOTO 6

NOTICE

If the SCOBY, the starter culture, is introduced to hot water then it result in undesirable death of useful bacteria that is needed to produce the material. The contact between metal and starter culture should be avoided aswell and therefore the material for the container should be made of either glass of plastic.

The growth of the bacterial cellulose film is temperature dependant, meaning that it will grow faster in warmer temperatures rather than cooler.

4.2.1 Case: “Grow Your Lamp!”

In my case I have started the process on 1st of July 2017. The day before I retrieved two pieces of the starter culture from ChemArts course tutor. I made 4 litres of tea liquid with green Sencha tea, 400g of caster sugar and 400ml of rice wine vinegar. I divided the liquid between two containers and placed one SCOBY per container, one as it was and the other cut in half. Covered the containers with muslin cloth and placed them to my kitchen cabinet.

After 10 days, on 10th of July, I checked on the project and noticed that new SCOBY have appeared to the surfice. It was almost 1 centimeter in thickness and bright white in colour.(Photo 5) The Kombucha liquide still smelled sweet wth a hint of tanginess to it. I covered it up again to protect it from fruit flies and other insects.

29th of July I took another peak to ensure that there is enough of liquide for the scoby to grow in and added few drops of red food colouring into the circular container.

Exactly one month after I decided to harvest the SCOBYs and start the drying prosess. They ware very heavy, due to high water content and weighing 296g the circular and 396g the bigger and retangular one. The colouring that I have added just few days before have made a huge diffrence in colour of the material and I was really pleased with that.

I have researched thet you are supposed to dry the material on wood boards, but this would result in flat material. Instead I decided to give some shape to them and placed the circular one to dry over a upside down colander and the rectangular over a medium-high vase. (Photo 7) I tried to dry them in shape but they lost the shape right after I removed them from the homemade “moulds”. Now they just hang freely and resemble upside-down flowers. (Photo 8)

PHOTO 7

Two weeks in drying and the scoby have turned to leather like material. I could still detect some dampness to it. The material was flexible due to the dampness and it lasted until thy were presented in Aalto Learning Center fuayer and lit for 24/7. Even though the light source was LED, it still generated some warmth that dryed the material completely.

When lit, the texture comes apperant and reminds so much of leather. Their colour is very interesting. The red one deepened in colour but it still has it`s luminous properties. Other one stayed natural and have a really weird look to it, I have not yet decided on either I hate it or love it. I guess that somehow the combination of the colour and texture of the material resembles too much of human skin and therefore people tend to have strong feelings about it. (Photo 8)

In contradictory, the sweet-tangy smell can still be detected, quite easily. I doubt that they ever be completely odourless.

5. ANALYSIS

5.1 Sustainability

The material is naturally sustainable, there is no threat that we ever will run out of the material or the ingredients that are needed for growing process. The materials like sugar and tea both come from plants that are commonly grown and reachable all-over the world.

When analysing the bacterial cellulose and "Grow Your Lamp" product in terms of cradle-to-cradle principles, there is possibility for upcycling.

The visualisation (Figure1), explains how the material could be recycled to grow new material after the products life cycle finishes. When the products life span ends, the bacterial cellulose can be extracted from the luminaires and reused as a starter culture to grow more of this material. Therefore, it is sustainable material and suited for cradle-to-cradle principles. For such reuse, it is incredibly important that no toxic dyes and other chemicals are used when producing the material or while using it. Therefore, it is continuous and never ending cycle.

PHOTO 8

5.2 Biodegradability

As a biological product, bacterial celluloses ability to biodegrade is its best asset and in the same time also its worst property. Bacterial cellulose is hundred percent biodegradable material.

Susan Lee have stated that her garments made of bacterial cellulose for the BIocouture, degrade while worn and she is currently working on solution that could stop or slow down the biodegrading process. (Lee, 2017)

For the sake of biodegrating it is important to use food grade dyes when dyeng the material it is easy to do so by applying food dye into the growing liquide at the end of the growing period.

Wood is also biodegradable material and the light fixtures could be used again.

5.3 Physical Properties

The Chart 1 shows different materials stiffness's in comparison to bacterial cellulose. The values are given in Young`s module. Interesting fact is that wood, cut along the grain) is ten times more elastic than bacterial cellulose, wood being 4GPa and bacterial cellulose 30-40 GPa. Glass stiffness wary greatly, depending to its consistency and thickness between 50-90.

Due to the material high mechanical strength, it could be possible to use the material as a part of a seating furniture as they require this kind of property to carry a weight of average man. To design seating furniture for example a chair, material as wood or metal are still needed for frame. The bacterial cellulose can be the substitute material for textile, leather and other soft materials, that are usually used for this kind of purpose.

Another meaningful property is bacterial cellulose`s stability towards high temperatures, big advantage over most textiles and paper that are ordinarily used for lamp shades. The materials stability to endure high temperatures makes it safe to use in lights and even in close contact with light sources.

5.4 Everyday usability

I have some concerns regarding the everyday usability of the lights, even though the material itself is strong and its texture and appearance are interesting when lit, that specific smell is still present even 8 months after harvesting the material. The odour might be pleasant to some users but it is quite strong and might not be as appealing to other users. The odour of fermented tea is not irritating because the material is hypoallergenic and is used on open wounds as a protective tissue and, in the medical field. Even though the odour will not cause allergies it would be considered as one of the materials limitations.

5.5 Economic viability

The fabrics growth period, was a continuous part of the project, in which several "batches" of fabric were grown, to allow for further experimentation. During this process, it was interesting to note the variation in thickness of the material, (and consequently translucency), from batch to batch.

The growth period also varied slightly. These variations may have been due to several reasons, these being, the pH, temperature, and carbon and nitrogen levels in the growth bath, which can all contribute to either help or hinder the yield of cellulose from the bacteria. Although in this situation, the batches of growth were not controlled to differ, it may be interesting to experiment with this in the future, to the fabric to specific fineness requirements. It is also important to note, that during the performance testing, different variants of the fabric were tested, and there was little to no difference between the samples, in terms of performance

PHOTO 9

capabilities, but rather they only differed in aesthetic and dimensional properties.

One major limitation that arose from this phase of experimentation, was the time restraints on the project, and the growth time for the fabric. Ideally it would have been beneficial to grow a larger amount of the fabric, to allow for more testing, and to produce an actual product that hypothetically could be sold and marketed. However due to the time constraints, it was not possible to do so. This also poses an issue for future production, as time is of the essence in terms of productivity, and can be a major factor in determining the economic feasibility of a product in the market.

6. CONCLUSIONS AND IMPLICATIONS

The research has provided some insightful information about the functionality and properties of microbial cellulose and guide on how to grow it at home. The material holds great potential for the industry of furniture design. The material can be grown from few simple ingredients, which can be reused to further grow more fabric. It is also possible to use food industry waste to make the growth liquid. Therefore, proving it to be a sustainable production method.

However, its limitation is the time-consuming growth process and therefore, (Rani, et al., 2011) at this stage the production is not economically viable. The material is 100% biodegradable, which is an enormous improvement compared to other materials used in furniture design, and could mean the potential for new environmentally friendly products soon.

Further research would support what specific conditions would be needed to determine different thickness' and weights of the fabric. This would help designers on to grow the exact material with the properties that is needed for their project.

I have noticed that people and designers know very little about cellulose and even less about bacterial cellulose. Everyone who have seen the lamps, have been incredibly interested on the growing process and properties of the material.

I would like to try, in near future, to use the material in seating furniture because of the material supposedly have the required strength to hold a person. I am also interested in growing the material in silicone containers that the material grows in shape of the container. The phenomena that I have learned by accident when growing samples for ChemArts project.

The materials formability is most important property in field of design. Growing bacterial cellulose into desired shape is the next research topic because usually the SCOBY grows on top of the container because its need for oxygen. However, small amounts of oxygen might be penetrating through the silicone moulds and causing the SCOBY to grow in shape of silicone container.

PHOTO 10

PHOTO 11

7. PHOTO CREDITS

Monika Faidi: 3; 6; 8

Eeva Suorlahti: cover photo; 1; 4; 9; 10

Helena Manner: 2; 5; 7; 11

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